

Associated production of the heavy charged gauge boson W_H and a top quark at LHC

Qing-Guo Zeng^{1,2}, Shuo Yang^{3†}, Chong-Xing Yue^{1*}, and You Yu¹

¹ *Department of Physics, Liaoning Normal University, Dalian 116029, China*

² *Department of Physics, Shangqiu Normal University, Shangqiu 476000, China*

³ *Physics Department, Dalian University, Dalian, 116622, China* *

Abstract

In the context of topflavor seesaw model, we study the production of the heavy charged gauge boson W_H associated with a top quark at the LHC. Focusing on the searching channel $pp \rightarrow tW_H \rightarrow t\bar{t}b \rightarrow l\nu jjbbb$, we carry out a full simulation of the signal and the relevant standard model backgrounds. The kinematical distributions of final states are presented. It is found that the backgrounds can be significantly suppressed by sets of kinematic cuts, and the signal of the heavy charged boson might be detected at the LHC with $\sqrt{s} = 14$ TeV. With a integrated luminosity of $\mathcal{L} = 100 \text{ fb}^{-1}$, a 8.3σ signal significance can be achieved for $m_{W_H} = 1.6$ TeV.

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*cxyue@lnnu.edu.cn

† yangshuo@dlu.edu.cn

I. INTRODUCTION

The standard model (SM) of particle physics is one of the most successful theories over the past decades which describes a variety of experimental results. However, the theoretical shortcomings of the SM, such as quadratic divergencies, the triviality of a ϕ^4 theory, etc., suggest that it should be embedded in a larger scheme. Many popular new physics models beyond the SM have been proposed, and some of which predict the existence of the new gauge bosons with masses at the TeV order. Thus, search for extra gauge bosons provides a common tool in quest for new physics at the LHC. In this paper, we study the signal of the heavy charged gauge boson W_H in topflavor seesaw model at the LHC.

It is interesting to note that only the top quark mass lies at the same mass scale of weak gauge bosons, while all other fermions are provided with masses less than a few GeV. This suggests that the top quark sector may involve some new gauge dynamics at the weak scale in contrast to all light fermions. Topcolor seesaw models employ strong $SU(3)$ top gauge group with singlet heavy quarks to address this mass hierarchy in fermion sector [1]. As an alternative, the topflavor seesaw model was proposed [2]. In topflavor seesaw model, the top sector experiences a new $SU(2)_t$ gauge interaction (Type I) ¹. The gauge group of topflavor seesaw model is $SU(3)_c \otimes SU(2)_t \otimes SU(2)_f \otimes U(1)_y$. In this model, the first two family fermions are singlets under the new $SU(2)_t$ gauge interaction. At the same time, a doublet of spectator quarks $S = (T, B)^T$ is introduced to cancel the theory anomaly for the third family. Two Higgs doublets Φ_1 and Φ_2 are introduced to spontaneously break gauge group $SU(3)_c \otimes SU(2)_t \otimes SU(2)_f \otimes U(1)_y$ down to the gauge subgroup $SU(3)_c \otimes U(1)_{em}$. Thus, two neutral physical Higgs boson h^0 and H^0 are predicted, in addition to the heavy bosons (W_H, Z_H). It is exciting that LHC has discovered a Higgs-like boson with mass around 125 GeV [3, 4], which coincides with the light Higgs h^0 predicted in the topflavor seesaw model [5].

In topflavor seesaw model, in order to address the mass hierarchy in fermions, only the top-sector enjoys the extra $SU(2)_t$ gauge interaction which is stronger than the or-

¹ The topflavor seesaw models could be implemented by introducing additional $SU(2)_t$ (TypeI) or $U(1)_t$ (Type II) gauge group[2]. In this paper, we only focus on the Type I realization.

dinary $SU(2)_f$ (associated with all the other light fermions). After the gauge symmetry breaking $SU(2)_t \times SU(2)_f \rightarrow SU(2)_L$ at a high scale u , the heavy gauge bosons which are combinations of the corresponding broken gauge fields of $SU(2)_t$ and $SU(2)_f$ obtain mass. This results in the coupling of W_H with tb is enhanced by the mixing parameter $1/x$ while the couplings of W_H with light fermions are suppressed by a factor of x [5]. Here, x is the ratio of the gauge coupling g_1 of $SU(2)_f$ to the gauge coupling g_0 of $SU(2)_t$ and it is constrained to be $x^2 \ll 1$ in this construction. This feature of topflavor seesaw model is different from those in many new physics model with heavy W_H including Kaluza-Klein theories of extra dimensions - as the excitation of the W [6], little Higgs theories - as the gauge bosons of the extended symmetry [7], several other well-motivated extensions of the SM [8–12]. In this paper, we study the production of W_H associated with a top quark followed by the decay $W_H \rightarrow tb$. This process provides an independently test of the $W_H \bar{t}b$ coupling which is closely relevant to the model feature.

This paper is organized as follows. In section II, we give a brief review of topflavor seesaw model and show relevant couplings for our calculation. In section III, the phenomenological analysis and numerical calculations for the production of the heavy charged gauge boson W_H in association with a top quark are presented. Our conclusions are given in section IV.

II. A BRIEF REVIEW OF TOPFLAVOR SEESAW MODEL

The topflavor seesaw model [2], in which the top sector experiences a new $SU(2)_t$ gauge interaction, is based on gauge group $SU(3)_c \otimes SU(2)_t \otimes SU(2)_f \otimes U(1)_y$. The corresponding three gauge couplings of the gauge group $SU(2)_t \otimes SU(2)_f \otimes U(1)_y$ are g_0, g_1, g_2 . Two Higgs doublets Φ_1 and Φ_2 are invoked to spontaneously break $SU(3)_c \otimes SU(2)_t \otimes SU(2)_f \otimes U(1)_y$ down to the residual symmetry $SU(3)_c \otimes U(1)_{em}$. The Higgs doublet Φ_1 with a nonzero vacuum expectation value (VEV) u break $SU(2)_t \otimes SU(2)_f$ down to the SM gauge group $SU(2)_L$, and the Higgs doublet Φ_2 with a VEV v break $SU(2)_L \otimes U(1)_y$ down to the SM gauge group $U(1)_{em}$. This kind of breaking pattern makes that this model contains extra massive color-singlet heavy gauge bosons W_H and Z_H , in addition to two neutral physical Higgs boson h^0 and H^0 .

The structure of topflavor seesaw model including its Higgs, gauge and top sectors has been systematically studied in Refs. [2, 5]. In this work, we aim to study the production of the heavy charged boson W_H at the LHC. The couplings of the heavy charged boson W_H to ordinary particles, which are related to our calculation, are given by [5],

$$\mathcal{L}_{\mathcal{W}_H \mathcal{F} \bar{\mathcal{F}}} = \frac{-ixg}{\sqrt{2}} \bar{f} \gamma_\mu P_L V_{\bar{f}f'} f' W_H^+ + \frac{i(1-rx^2)g}{\sqrt{2}x(1+r)} \bar{t} \gamma_\mu P_L b W_H^+ + h.c., \quad (1)$$

and

$$\mathcal{L}_H = -ix(c_\alpha - ys_\alpha)gm_w W_H^+ W^- h^0 + ix(s_\alpha + yc_\alpha)gm_w W_H^+ W^- H^0, \quad (2)$$

where we have defined the ratios $x \equiv g_1/g_0$, $r \equiv k^2/M_S^2$, and $y \equiv v/u$. Here M_S denotes the mass eigenvalues parameter of heavy quarks (T, B), and the parameter k is expected to be of $\mathcal{O}(M_S)$. And α represents the mixing angle between physical Higgs bosons (h^0, H^0) and their weak eigenstates. The Higgs-like particle found by LHC agrees well with the SM prediction which suggests a small α in the range $0 < \alpha \leq 0.2\pi$ [3–5].

The coupling of W_H with light gauge bosons W and Z is given by

$$g_{W_H W Z} = \frac{-ix^3 y^2}{c_W^2} G_{WWZ}^{SM}, \quad (3)$$

where G_{WWZ}^{SM} represents the coupling constant of WWZ in the SM.

A detailed analysis of direct search for the topflavor seesaw model at the LHC and the constraints on this model of electroweak precision measurements are presented in Ref. [5]. In the topflavor seesaw model, the heavy spectator quarks (T, B) are vector-like under $SU(2)_L$, so the fermionic contributions to oblique corrections can be fairly small in decoupling limit. The higgs sector contributions are relevant to the masses of the physical Higgs bosons (h^0, H^0) and the mixing angle α . The contributions from gauge sectors are dependent on the masses of heavy gauge bosons W_H/Z_H and the mixing parameter x . After deducing the contributions to electroweak precision parameters from gauge, Higgs and fermion sectors, it is found that at 95% C.L., there should be $m_{W_H} \gtrsim 0.45 \sim 1$ TeV for a wide H^0 mass range up to 800 GeV with the inputs $\alpha = 0.1\pi \sim 0.2\pi$ and $M_T = 4$ TeV [5].

The ATLAS and CMS collaborations have been actively searching for the new gauge boson W_H at the LHC [13, 14]. They mainly focus on the sequential standard model (SSM), where the couplings of W_H with fermions equal to the corresponding SM couplings.

Focusing on the process $pp \rightarrow W_H \rightarrow l\nu$, the lower limits for the W_H mass of 2.15 TeV [15] and 2.5 TeV [16] have been obtained at the LHC by the ATLAS and CMS experiments respectively. CMS has also searched for the process $pp \rightarrow W_H \rightarrow WZ$ using the fully leptonic final state and has set the lower limit for W_H bosons $m_{W_H} > 1.14$ TeV [17]. However, different scenarios have different phenomenological features. The direct search constraints can be relaxed in some models. In the topflavor seesaw model, the couplings of heavy bosons W_H/Z_H with light fermions are suppressed by the small mixing angles, which are of the order of $\mathcal{O}(x)$. Hence, the production rate for the process $pp \rightarrow W_H$ is suppressed by a factor of x^2 and the decay rates for $W_H \rightarrow f\bar{f}'$ and $W_H \rightarrow WZ$ are also suppressed. Thus, the corresponding signals are hard to be detected.

The most stringent limit on the W_H mass comes from $pp \rightarrow W_H \rightarrow tb$ given by the CMS collaboration [13]. CMS has excluded right handed W_H with mass below 1.85 TeV via this channel. Unlike SSM model, the couplings of W_H to light fermions are suppressed by x while the coupling of $W_H tb$ is enhanced by a factor $1/x$ in the topflavor seesaw model. Considering the branching ratios, the W_H signal rate of $\sigma \times Br$ is smaller than that of SSM by about a factor of $4x^2$. With the sample input $x = 0.15$, it is found a 95% C.L. lower limit on W_H mass, $m_{W_H} > 1.0$ TeV, from the CMS data [5][13, 16, 17].

III. NUMERICAL RESULTS AND DISCUSSION

Before studying the process $pp \rightarrow tW_H$, we firstly consider the possible decay modes of the heavy charged gauge boson W_H . Once produced at the LHC, the heavy boson W_H can decay into $f\bar{f}'$, $t\bar{b}$, Wh^0 , WH^0 and WZ . The partial widths of W_H decaying to a pair of fermions are

$$\Gamma(W_H \rightarrow f\bar{f}') = \frac{g^2 x^2}{16\pi} |V_{f\bar{f}'}|^2 m_{W_H}, \quad (4)$$

$$\Gamma(W_H \rightarrow t\bar{b}) = \frac{g^2}{16\pi} \left[\frac{1 - rx^2}{x(1+r)} \right]^2 m_{W_H} \left(1 - \frac{m_t^2}{m_{W_H}^2}\right) \left(1 - \frac{m_t^2}{2m_{W_H}^2} - \frac{m_t^4}{2m_{W_H}^4}\right). \quad (5)$$

Likewise, the partial widths of the W_H decaying to W boson and Higgs are,

$$\begin{aligned} \Gamma(W_H \rightarrow Wh^0) &= \frac{g^2 [x(c_\alpha - ys_\alpha)]^2}{192\pi m_{W_H}^5 m_W^2} ((m_{W_H}^2 + m_W^2 - m_{h^0}^2)^2 - 24m_{W_H}^2 m_W^2) \\ &\quad \times \sqrt{(m_{W_H}^2 - (m_W^2 + m_{h^0}^2)^2)(m_{W_H}^2 - (m_W^2 - m_{h^0}^2)^2)}, \end{aligned} \quad (6)$$

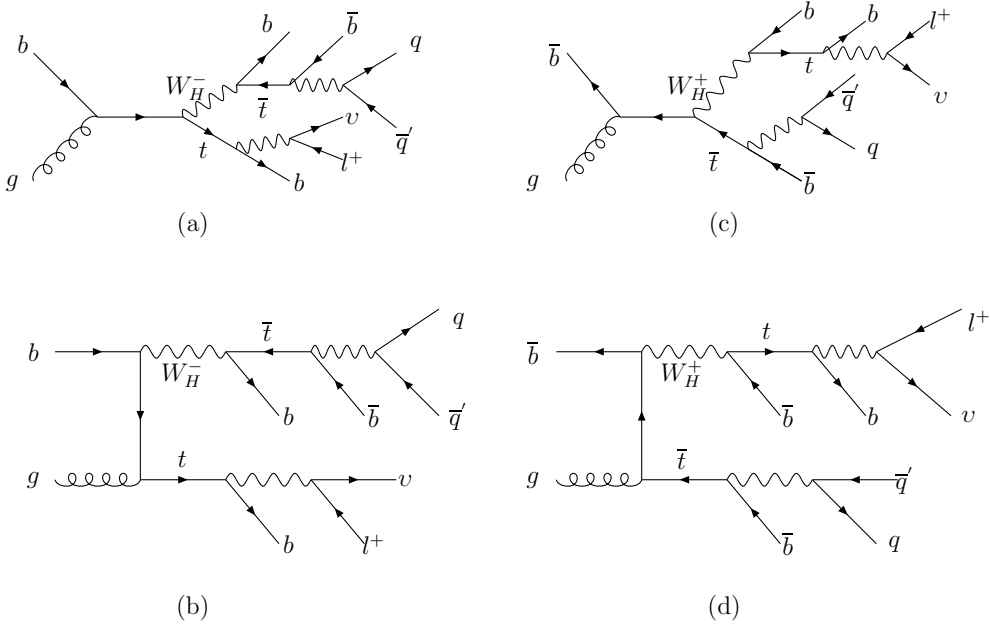


FIG. 1: The partonic level process for a W_H in association with a top quark production and decay in hadronic collisions.

$$\Gamma(W_H \rightarrow WH^0) = \frac{g^2[x(s_\alpha + yc_\alpha)]^2}{192\pi m_{W_H}^5 m_W^2} ((m_{W_H}^2 + m_W^2 - m_{H^0}^2)^2 - 24m_{W_H}^2 m_W^2) \times \sqrt{(m_{W_H}^2 - (m_W^2 + m_{H^0}^2)^2)(m_{W_H}^2 - (m_W^2 - m_{H^0}^2)^2)}. \quad (7)$$

Noting the coupling $g_{W_H W Z} \propto (x^3 y^2)$, and $x^2, y^2 \ll 1$, we neglect the $W_H \rightarrow WZ$ decay channel here.

Here, we calculate the branching ratios (BRs) of W_H . It is found that the BR of $W_H \rightarrow tb$ is dominant and the BRs of other decay modes $W_H \rightarrow ff'$, $W_H \rightarrow Wh^0$ and $W_H \rightarrow WH^0$ are tiny. This is because the coupling of $W_H tb$ is roughly proportional to $1/x$ while the other decay modes are suppressed by the relevant couplings.

Furthermore, we show the cross section for process $pp \rightarrow tW_H$ (include both $g\bar{b} \rightarrow \bar{t}W_H^+$ and $gb \rightarrow tW_H^-$) as a function of the heavy boson mass m_{W_H} with $\sqrt{s} = 14$ TeV in Fig. 2. In calculations, we use the parton distribution functions given by CTEQ6L1 [19]. The renormalization scale μ_R and the factorization scale μ_F are chosen to be $\mu_R = \mu_F = m_{W_H}$, and the strong coupling constant α_S is taken as $\alpha_S(m_Z) = 0.118$. The SM input parameters are taken as $m_t = 173.2 \text{ GeV}$ and $S_w^2 = 0.231$ [20]. As shown in the Fig. 3, the cross sections decrease as m_{W_H} increases, which are in the ranges of hundreds

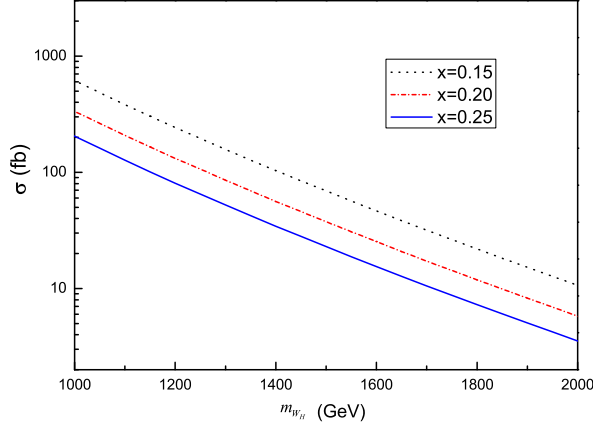


FIG. 2: The cross section for the process $pp \rightarrow tW_H$ as function of the heavy boson mass m_{W_H} for $r = 1$ and three typical values x at the LHC with $\sqrt{s} = 14$ TeV.

fb to several fb , for $m_{W_H} = 1000 GeV \sim 2000 GeV$ and $x = 0.15 \sim 0.25$. For a typical mass $m_{W_H} = 1.6$ TeV ($x = 0.2$), there will be about 2500 tW_H events at the LHC with a integrated luminosity $100 fb^{-1}$. The couplings of W_H with $t\bar{b}$ is enhanced by about a factor of $1/x$ in topflavor seesaw model. Hence, the cross section for process $pp \rightarrow tW_H$ in topflavor seesaw model is larger than that in SSM, top-philic W' model [8], little Higgs models [21], and left-right twin Higgs model [22].

In this paper, we will focus on the tW_H production followed by the dominant decay channel $W_H \rightarrow t\bar{b}$. And we demand a hadronic decay of the antitop $\bar{t} \rightarrow \bar{b}W^- \rightarrow \bar{b}jj$ and leptonic decay of the top quark $t \rightarrow bW^+ \rightarrow bl^+\nu_l$ where the charged lepton provides detector trigger ². Thus, in the following, we investigate the signal processes

$$pp \rightarrow g\bar{b} \rightarrow \bar{t}W_H^+ \rightarrow \bar{t}t\bar{b} \rightarrow W^- \bar{b}t\bar{b} \rightarrow jj\bar{b}l^+\nu b\bar{b}, \quad (8)$$

$$pp \rightarrow gb \rightarrow tW_H^- \rightarrow t\bar{t}b \rightarrow W^+ b\bar{t}b \rightarrow l^+\nu bjjb\bar{b}. \quad (9)$$

Both electrons and muons are considered for the positive charged lepton in our analysis. Thus the signal includes a isolated charged lepton, five jets, and a large missing transverse

² Ref. [23] finds that the signal for heavy charged gauge boson could be extracted in full hadronic mode with the help of the jet substructure technique.

momentum \cancel{E}_T from the missing neutrino. The Feynman diagrams for the signal processes are shown in Fig. 1. MadGraph/MadEvent [24] is adapted to generate both the signal and background processes.

For the $bbbjjl\nu$ signal, the SM backgrounds mainly come from the irreducible $t\bar{t}b$ background and the reducible $t\bar{t}j$ background, where the light jet j means the light-flavor quarks or gluons.

$$pp \rightarrow t\bar{t}b \rightarrow b\bar{b}bjjl^+\nu, \quad (10)$$

$$pp \rightarrow t\bar{t}j \rightarrow b\bar{b}bjjl^+\nu. \quad (11)$$

The other SM background processes, eg, $Wjjjjj$, $WWjjj$ and $WZjjj$, etc. can be dramatically reduced by the cuts adopted in the following and therefore we neglected them here.

In order to identify the isolated jet (lepton), we define the angular separation between particles i and j as

$$\Delta R_{ij} \equiv \sqrt{(\Delta\phi_{ij})^2 + (\Delta\eta_{ij})^2}, \quad (12)$$

where $\Delta\phi_{ij} = (\phi_i - \phi_j)^2$ and $\Delta\eta_{ij} = (\eta_i - \eta_j)^2$. $\eta_i(\phi_i)$ denotes the rapidity (azimuthal angle) of the related lepton (jet).

The basic acceptance cuts, referred to as cut I, are applied for the signal and background events,

$$\begin{aligned} p_{Tj} &\geq 25\text{GeV}, & |\eta_j| &\leq 2.5, \\ p_{Tl} &\geq 25\text{GeV}, & |\eta_l| &\leq 2.5, \\ \Delta R_{jj,jl} &\geq 0.4, & \cancel{E}_T &\geq 25\text{GeV}. \end{aligned} \quad (13)$$

Here, p_{Tj} (p_{Tl}) is the jet (lepton) transverse momentum, \cancel{E}_T denotes the missing transverse momentum from the invisible neutrino in the final state. The effects of these cuts are shown in Tables I and II.

To make our analysis more realistic, we simulate detector resolution effects by smearing the lepton and jet energies according to the assumed Gaussian resolution parametrization

$$\frac{\delta(E)}{E} = \frac{a}{E} \oplus b, \quad (14)$$

where $\frac{\delta(E)}{E}$ is the energy resolution, a is a sampling term, b is a constant term, and \oplus denotes a sum in quadrature. We take $a = 5\%$ and $b = 0.55\%$ for leptons, and take $a = 100\%$ and $b = 5\%$ for jets [25, 26].

After the basic cuts to simulate the detector acceptance, we further employ optimized kinematical cuts to reduce the backgrounds based on the kinematical differences between the signal and backgrounds. The signal events consist of five jets in the final state. These jets from the heavy boson W_H decay tend to have larger p_T than the jets in the background events. We order the jets by their p_T and present the normalized p_T distributions for the leading jet and the second jet in the signal events and background events in Fig. 3. The model parameters are set as $m_{W_H} = 1.25$ TeV and $(x, r, \alpha) = (0.20, 1, 0.13)$ in the signal process.

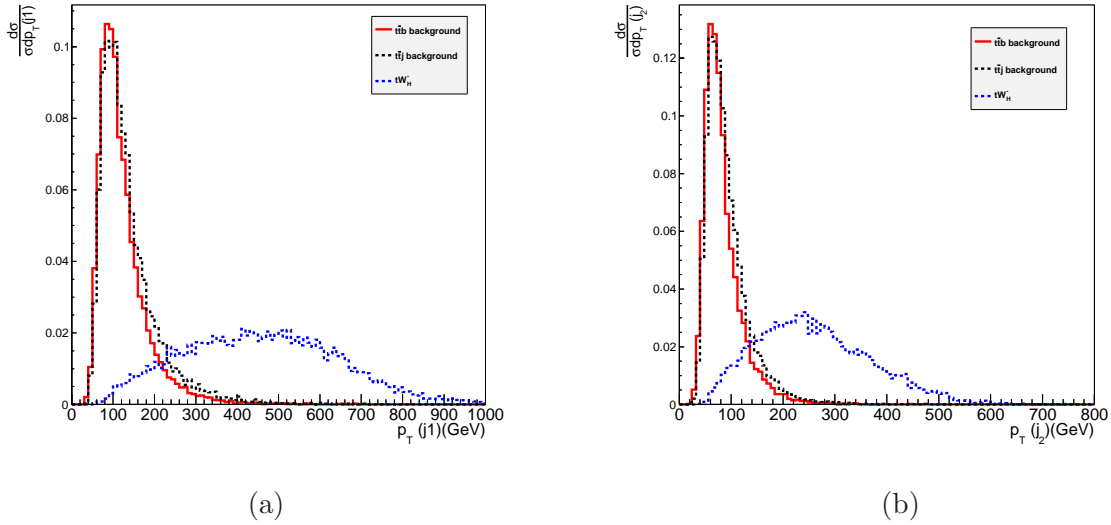


FIG. 3: Transverse momentum p_T distributions of the hardest jet (a) and the second hardest jet (b) in the signal and the SM backgrounds.

From Fig. 3.(a), we can see that the leading jet (j_1) in the signal events has much harder p_T distributions than the jet in the SM background events. This is because the hardest jet in the signal is mainly the b jet or the daughter-jet of the highly boosted top from $W_H \rightarrow t\bar{b}$ decay. Its p_T spectrum peaks around half of heavy boson mass. However, the top quarks in the SM backgrounds are mainly produced in the threshold region. Thus the jets from top quark decay in the backgrounds tend to be soft.

Similar to the leading jet, the second jet (j_2) in the signal is harder than that in the backgrounds as displayed in Fig. 3.(b). Furthermore, the normalized H_t distributions, i.e., the scalar sum of the p_T 's for all the visible particles in the final state, are shown in Fig. 4. The model parameters are set as $m_{W_H} = 1.25$ TeV and $(x, r, \alpha) = (0.20, 1, 0.13)$ in the signal process.

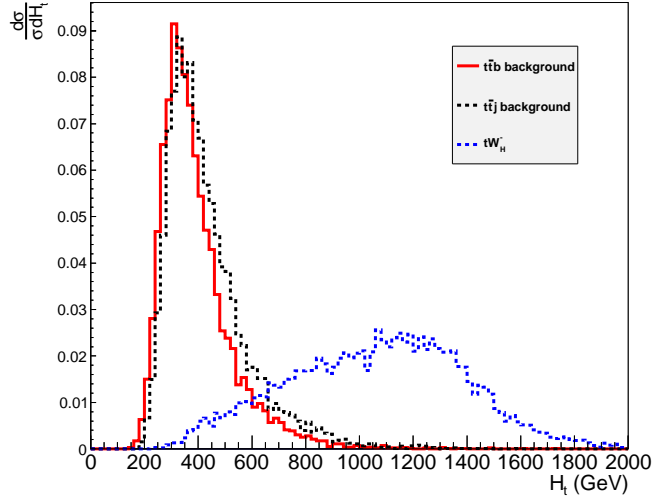


FIG. 4: Total transverse momentum H_t distributions of the signal and the SM backgrounds.

To purify the signal, a set of hard p_T cuts are further adopted for $m_{W_H} = 1.25$ TeV, based on above analysis, as follows:

$$p_T(j_1) \geq 250 \text{ GeV}, \quad p_T(j_2) \geq 140 \text{ GeV}, \quad H_t = \sum_{n=1}^5 p_T(j_n) + p_T(l^+) \geq 800 \text{ GeV}. \quad (15a)$$

For $m_{W_H} = 1.6$ TeV, a similar set of cuts

$$p_T(j_1) \geq 350 \text{ GeV}, \quad p_T(j_2) \geq 180 \text{ GeV}, \quad H_t = \sum_{n=1}^5 p_T(j_n) + p_T(l^+) \geq 1200 \text{ GeV} \quad (15b)$$

are adopted. These optimized cuts in Eq. (15) are referred to as cut II, and the efficiencies of these cuts are shown in Tables I and II.

In order to suppress the $t\bar{t}j$ background, it is crucial to identify the extra jet (denoted as j_{extra}) produced in association with the $t\bar{t}$ pair as a b jet. Following the reconstruct

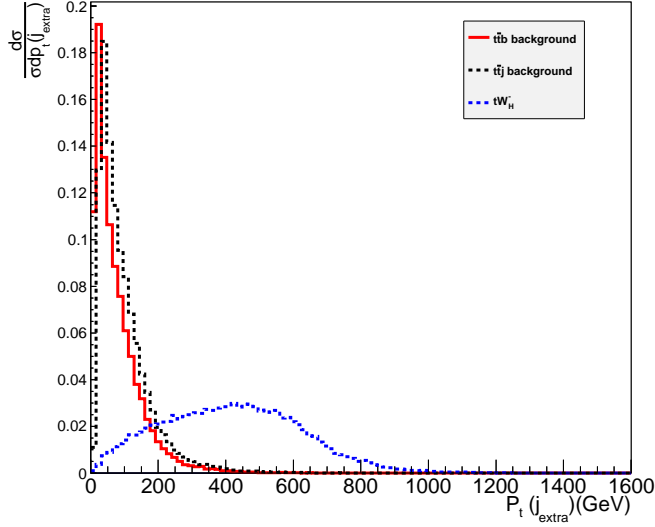


FIG. 5: Transverse momentum p_T distributions of the extra jet in the signal and the SM backgrounds.

scheme [8], we apply the minimal χ^2 -template method which based on the W boson and top quark masses to pick out the extra jet,

$$\chi^2 = \frac{(m_t - m_{j\nu})^2}{\delta m_t^2} + \frac{(m_t - m_{jj})^2}{\delta m_t^2} + \frac{(m_W - m_{jj})^2}{\delta m_W^2}, \quad (16)$$

where δm_t and δm_W are chosen to be 15 GeV and 10 GeV, respectively, which account for the detector resolution capability. The m_W and m_t are taken as 80.4 GeV and 173.2 GeV, respectively.

In Fig. 5, we present the normalized p_T distributions of the extra jet for $W_H = 1.25$ TeV and $(x, r, \alpha) = (0.20, 1, 0.13)$. The extra jet in association with $t\bar{t}$ in the SM backgrounds comes mainly from QCD radiation, while the extra jet in the signal is often predominately from the heavy W_H decay. Hence, it is obvious that the extra jet in the signal has much harder p_T distributions than the extra jet in the SM backgrounds. Here, we further take cut on extra jet,

$$p_T(j_{extra}) \geq 200 \text{ GeV}. \quad (17)$$

Similarly, $p_T(j_{extra}) \geq 400$ GeV is adopted for $m_{W_H} = 1.6$ TeV. After the extra jet is discriminated, we can further require it to be a b -jet. Here, we choose the tagging

	singnal			backgrounds	
	$x = 0.15$	$x = 0.20$	$x = 0.25$	$t\bar{t}b$	$t\bar{t}j$
cuts I	656	352	218	2.27×10^4	2.78×10^6
cuts II	453	247	152	231	2.86×10^4
b-tagging	272	148	91	139	286
cuts III	197	108	68	42	18
S/\sqrt{B}	25.4	13.9	8.78	—	

TABLE I: The event numbers of the signal and backgrounds at the 14 TeV LHC with an integrated luminosity of 100 fb^{-1} for $m_{W_H} = 1.25 \text{ TeV}$ and three values of x after each performed cut.

efficiency of b -jet as 60% and the mis-tagging efficiency of a light quark jet and gluon jet as 1% [26]. This b tagging cut could significantly suppress the $t\bar{t}j$ background.

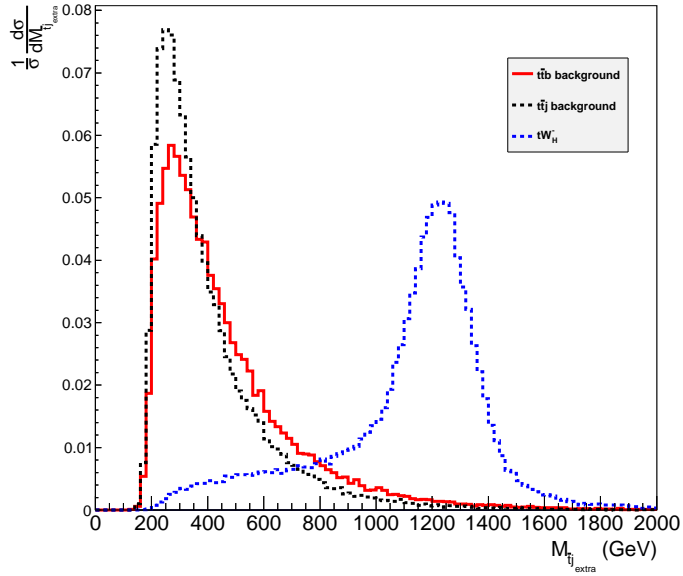


FIG. 6: Invariant mass distribution of the reconstructed \bar{t} and j_{extra} in the signal and the SM backgrounds.

After reconstructing the top pair and singling out the extra jet, it is easy to reconstruct the W_H . We present the normalized invariant mass distribution of the $m_{\bar{t}j_{extra}}$ in

Singnal	$t\bar{t}b$			
M (TeV)	1.25		1.60	
cuts I + II + III + b tagging	108		22	
backgrounds	$t\bar{t}b$	$t\bar{t}j$	$t\bar{t}b$	$t\bar{t}j$
cuts I + II + III + b tagging	42	18	2	5
S/\sqrt{B}	13.9		8.32	

TABLE II: The event numbers of the signal and backgrounds at the 14 TeV LHC with an integrated luminosity of 100 fb^{-1} for $(x, r, \alpha) = (0.20, 1, 0.13)$ and three values of m_{W_H} after each performed cut.

Fig. 6. It is shown that the signal distribution shows a sharp peak around the input value of $m_{W_H}=1.25$ TeV. However, the SM backgrounds exhibit a broad spectrum and peak in the low mass region. Thus we further require the invariant mass of the extra jet and t quark or \bar{t} quark to be around the heavy boson W_H mass window,

$$|m_{W_H} - m_{\bar{t}_{j_{extra}}}| < 200\text{GeV}, \quad |m_{W_H} - m_{t_{j_{extra}}}| < 200\text{GeV}. \quad (18)$$

The cuts in Eq. (18) can efficiently suppress the SM backgrounds while keep most of the signal. These cuts in Eq. (17) and Eq. (18) are referred to as cut III, and the efficiency of these cuts are shown in Tables I and II.

As shown in Table I, the sets of cuts significantly suppress the backgrounds. Supposing the integrated luminosity to be 100fb^{-1} at $\sqrt{s} = 14$ TeV, a large significance $S/\sqrt{B} = 8.78$ (25.4) can be achieved for 1.25 TeV mass W_H with $x = 0.25$ ($x=0.15$). In Table II, the case for W_H with mass $m_{W_H} = 1.6$ TeV and $(x, r, \alpha) = (0.20, 1, 0.13)$ are further considered. With a integrated luminosity of 100fb^{-1} , a statistical significance 8.32σ can be achieved for W_H with mass $m_{W_H} = 1.6$ TeV .

IV. CONCLUSIONS

Many new physics scenarios beyond the SM predict the existence of new heavy gauge boson. The discovery of heavy charged gauge bosons will be the smoking gun of new gauge group and provide an important hint on electroweak symmetry breaking.

In this paper, focusing on the channel $pp \rightarrow tW_H \rightarrow t\bar{t}b$, we have studied the potential for discovering the extra heavy gauge boson W_H predicted in topflavor seesaw model at the LHC. Studying the process $pp \rightarrow tW_H \rightarrow t\bar{t}b$ can independently test the $W_H\bar{t}b$ coupling and shed light on the flavor structure and the gauge structure of new physics models. In some new physics model [2, 8], the couplings of SM fermions to new gauge boson W_H are not universal. Especially, in the topflavor seesaw model, the couplings of W_H with $\bar{t}b$ is enhanced by a factor of $1/x$ while the couplings of W_H with light fermions are suppressed by a factor of x . After calculation, it is found that the cross section for tW_H production can reach tens fb for m_{W_H} in the mass range $1.2 \sim 1.7$ TeV. We further studied the different kinematic features of the signal $pp \rightarrow tW_H \rightarrow t\bar{t}b \rightarrow l\nu jjbbb$ and backgrounds. Our study shows that it is possible to discover the signal of W_H of topflavor seesaw model. The resonance peak in the invariant mass distribution of top quark and b-jet is a distinct signature of W_H discovery. Taking the $m_{W_H} = 1.6$ TeV and $(x, r, \alpha) = (0.20, 1, 0.13)$ as an example, the signal significance can reach 8.32σ at the LHC with $\sqrt{s} = 14$ TeV and luminosity $\mathcal{L} = 100 \text{ fb}^{-1}$.

Acknowledgments

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